Operational SSULI Algorithm for Dayside Ionosphere HmF2

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LONG-TERM GOALS

The ultimate goal of this research is the development of an operational algorithm for retrieving daytime ionospheric hmF2 from the measurement of the O II 83.4 nm emission feature. This algorithm will provide data for ingestion into ionospheric models. The reward of a successful algorithm is very high, as no capability presently exists to measure the global variation of hmF2 within the F-region of the ionosphere during the day. Further, this work will provide a new assessment of the state of the ionosphere during significant space weather events, which is critical to the use of GPS and other operational systems that rely on the propagation of radio waves within the near-Earth space environment. In addition, this research could lead to a method for global monitoring of the ionosphere and its response to solar, geomagnetic and lower atmospheric waves and tides.

OBJECTIVES

The technological objective of this research is to develop a new algorithm that can be used to obtain routine, global ionospheric measurements for incorporation into operational codes and assimilative ionospheric models, including the Global Assimilation of Ionospheric Measurements (GAIM) model. GAIM, used at AFWA as the state-of-the-art ionospheric predictive model for Navy and DoD needs, currently is limited by the absence of data that can be ingested to constrain the daytime hmF2 parameter. The hmF2 specifies the height of the peak of the ionosphere and is used as both a metric for the ionosphere and a parameter to specify the ionospheric density profile. The software to be developed will be directly applicable to dayside data from the Special Sensor Ultraviolet Limb Imager (SSULI) sensors on the DMSP F18-20 satellites. The proposed additional capability of the SSULI Ground Data Analysis Software (GDAS) to generate operational hmF2 values from 83.4 nm measurements would provide data that could be used as hmF2 parameter constraints with GAIM at AFWA. The scientific objective of this effort is to develop an understanding of the ionospheric response to variability in solar and geomagnetic forcing. In addition, this effort will lead to pioneering research in the fundamental physics behind the dayside 83.4 nm emission and the conditions under which it presents a viable measure of this ionospheric variability.

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14. ABSTRACT
The ultimate goal of this research is the development of an operational algorithm for retrieving daytime ionospheric hmF2 from the measurement of the O II 83.4 nm emission feature. This algorithm will provide data for ingestion into ionospheric models. The reward of a successful algorithm is very high, as no capability presently exists to measure the global variation of hmF2 within the F-region of the ionosphere during the day. Further, this work will provide a new assessment of the state of the ionosphere during significant space weather events, which is critical to the use of GPS and other operational systems that rely on the propagation of radio waves within the near-Earth space environment. In addition, this research could lead to a method for global monitoring of the ionosphere and its response to solar, geomagnetic and lower atmospheric waves and tides.

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APPROACH

The first task to this research is to implement and update existing software to permit production level processing of SSULI 83.4 nm limb intensity data. These data will be stored for subsequent analysis. Dr. Rebecca Bishop and her colleagues at The Aerospace Corporation will independently conduct a detailed hand-scaled analysis of ground based ionosonde data coincident with SSULI measurements. This hand-scaling effort provides a higher-quality ground truth assessment for comparison to the SSULI measurements. A subset of these coincident sets will be selected for a regression analysis, and the remaining coincident data will provide a basis for testing of the new empirical mapping from SSULI 83.4 nm to hmF2. A discrete inverse theory algorithm and code written by Dr. J. Michael Picone [2, 3] (formerly at NRL, now at George Mason Univ.) will then be used to fit the coincident SSULI limb intensity profiles. Relevant profile parameters will be identified and extracted from the fits to the measured profiles and compiled for regression analysis or testing of the new algorithm against ionosonde hmF2, as dictated by the previous step. A single variable regression analysis will then be used on the control data set to develop a statistical mapping of the previously described one or two SSULI limb intensity profile parameters to hmF2. The mapping that results from the regression analysis will be verified using the remaining SSULI data in the test set. The results will be verified with the hmF2 values obtained from coincident ionosonde measurements. After the single parameter regression analysis is completed, a multiple variable analysis will be conducted using the same approach to assess improvements that can be achieved in accuracy of ionospheric hmF2.

Dr. Picone will assist with updating and adapting his discrete inverse theory code as applied to this problem. He also will be available for consultation on scientific issues. Dr. Bishop and her colleagues at The Aerospace Corporation will provide ionosonde measurements.

WORK COMPLETED

The SSULI data from the DMSP F16 satellite have been processed and a database of limb profiles of the 83.4 nm emission has been compiled. Over 100 coincident ionosonde measurements have been obtained allowing up to 5 degree offsets in latitude and longitude and 15 minute separation in time. These windows were selected based on the scales of expected ionospheric variability as well as realistic expectations for a limited data set. The profiles have been fit using three implementations of the forward model: (1) three Chapman parameters in the forward model (NmF2, hmF2, and H_o) and an intensity scalar (j_o) to allow for variation in sensor responsivity over time, (2) same parameters as in case 1, but limiting the parameter space that each of the model parameters was allowed to search, and (3) completing the retrieval with an average j_o scalar identified in case 1 and not allowing it to vary from retrieval to retrieval. In addition, a rudimentary polynomial fit was conducted to each profile for comparison to the detailed fitting. Histograms of the scalars needed to adjust the basis ionospheres to fit the measured airglow profile using the first implementation are shown in Figure 1. This figure shows results from all available SSULI profiles, from which the subset of coincident measurements were selected. A single-variable regression has been completed for these profile fittings within the selected subset, comparing the ionosonde hmF2 with an effective SSULI hmF2 defined by the altitude of the peak of the emission profile. A multi-variable regression included both this effective hmF2 as well as the intensity at the most nadir point in the profile. Previous work [1] has indicated that these variables may contain the most information for correlation to the ionospheric hmF2.

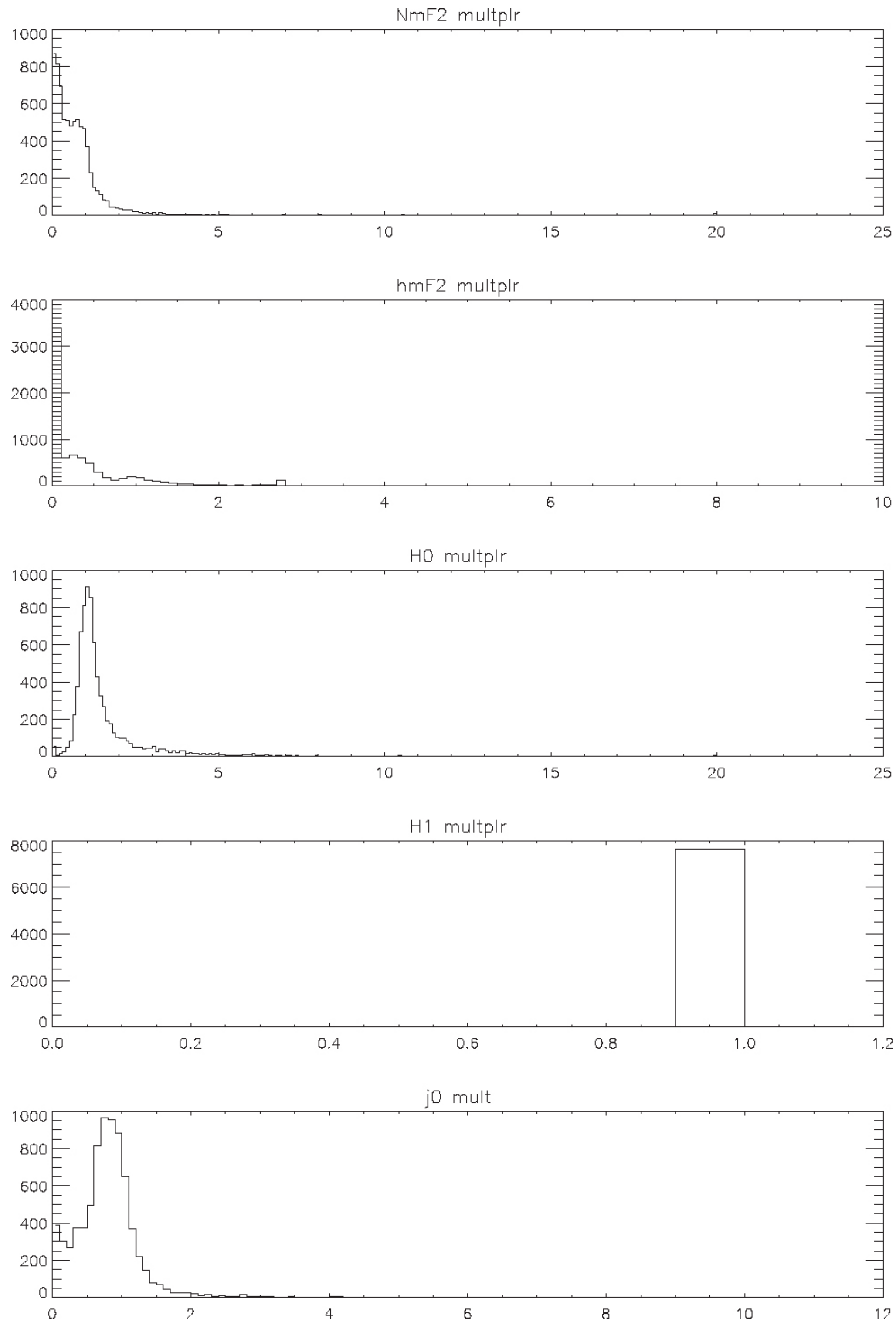

Figure 1. Results showing histogram of scalars applied to the IRI basis ionosphere Chapman parameters to fit the 83.4 nm limb profiles measured by SSULI, obtained for case (1) discussed in the text. The linear Chapman scale height parameter, H1, was not used in the current testing. A particularly interesting result is the double-peaked distribution of hmF2, indicating two classes of ionospheres measured during this time. The jo scalar shows the need for a minor intensity adjustment prior to implementing a full retrieval.

RESULTS

The primary result showed that the specification of the ionosphere using the proposed algorithm is complex and potentially impossible when the ionosphere hmF2 is below 300 km. All the SSULI F16 data were obtained near solar minimum and at geographic locations where the ionosphere is below this nominal cutoff, as shown in Figure 2. The complexity derives from the altitude separation between the initial source of the 83.4 nm emission lower in the atmosphere and the ionospheric layer that resonantly scatters the photons. As the ionosphere falls to lower altitudes, as it does during solar minimum, the measured profile appears to become more reflective of the initial source region and the ionospheric signature disappears. This is only a limitation of the method, and not a failure. Figure 3 demonstrates that the results are not impacted by the window of coincidence used, as there is no distinction in these data at different levels of coincidence. The algorithm may still be viable particularly as solar activity increases or in the afternoon sector when the ionosphere is markedly higher. The SSULI F16 data, on the other hand, were obtained in the morning local time sector during solar minimum, perhaps the worst possible conditions for such an algorithm to succeed. The greatly reduced quality of the SSULI F16 data provides an additional limitation that must be overcome for the development of a successful algorithm.

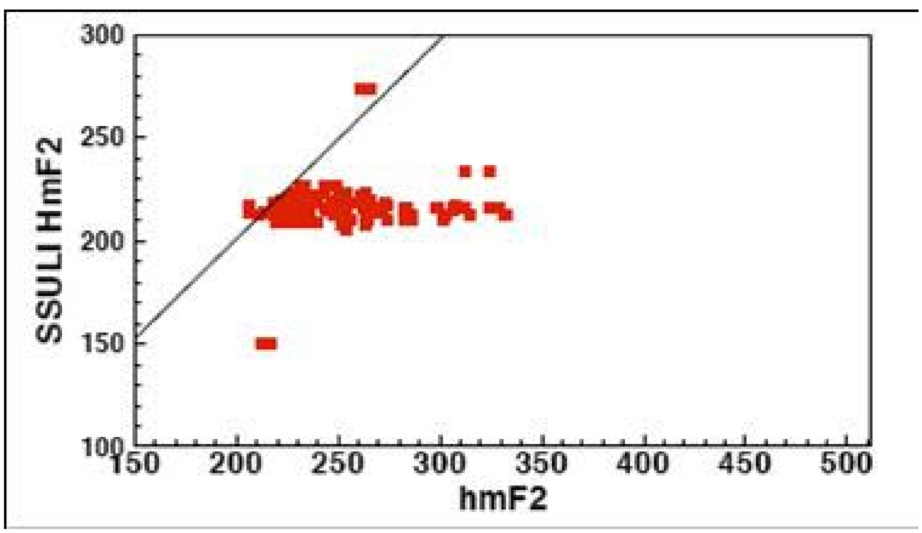

Figure 2. The effective hmF2 from the SSULI measurement given by the height of the peak of the emission profile, versus hmF2 ground truth measured by ionosondes. The ionosonde profiles show that all but a few measurements have hmF2 greater than 300 km. The correlation between the data is poor.

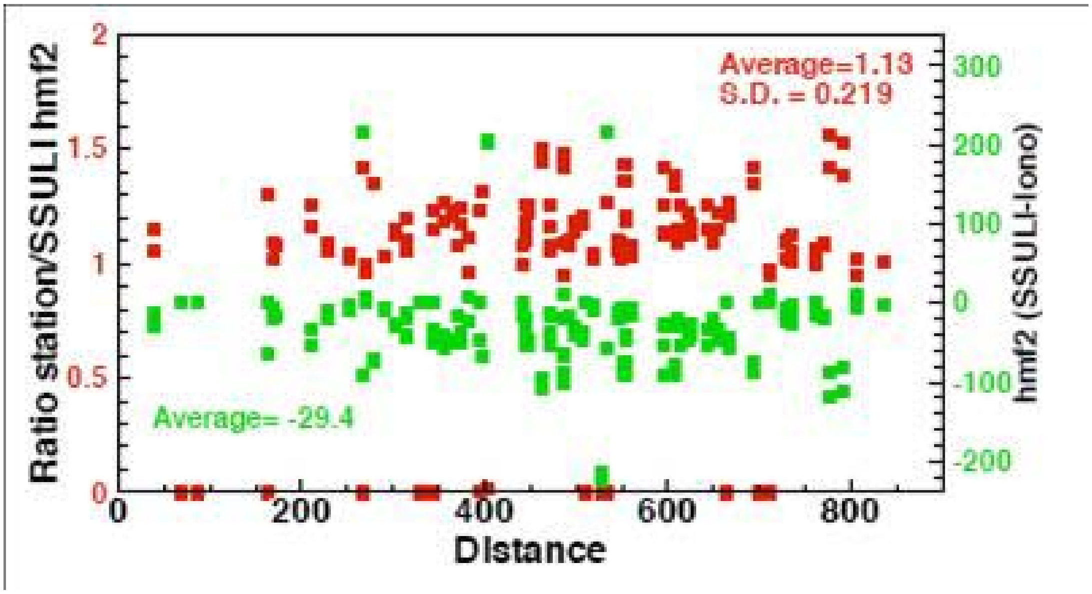

Figure 3. Ratio of SSULI to ionosonde measurement versus separation distance at time of coincidence. The correlation does not improve with smaller separation, suggesting the poor correlation is due primarily to the low ionospheric peak height.

IMPACT/APPLICATIONS

This result is the first effort to implement a dayside ionospheric remote sensing method. With the lessons learned from this initial work, it is expected that new avenues for development will proceed with the SSULI DMSP F18-F20 sensors. Sensor improvements made after the F17 mission should result in significantly higher fidelity measurements that can be used within the current effort. In addition, the Remote Atmospheric Ionospheric Detection System (RAIDS), recently launched and installed on the Japanese Kibo module of the International Space Station, will provide groundbreaking measurements of the 83.4 nm feature as well as the OII 61.7 nm emission that provides a separate measure of the initial source region. The information gained from this effort will drive the science requirements of the RAIDS EUV sensor and will provide new opportunities for the DMSP F18-F20 operational sensors.

RELATED PROJECTS

The Remote Atmospheric and Ionospheric Detection System (RAIDS) (https://raids.nrl.navy.mil/) will provide unique measurements of the OII 83.4 and 61.7 nm measurements. In addition to measuring 83.4 nm limb profiles, RAIDS will examine the intricate relationship between the initial source region and the ionospheric multiple scattering region. The lower altitude of the ISS compared to other available sensors provides a unique perspective on the physics of this problem, and will be invaluable in resolving the limitations and problems of the algorithm.

The SSULI sensors on the DMSP F18-F20 will provide a high quality set of 83.4 nm measurements for additional evaluation of the potential of the algorithm investigated in this effort.

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